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October 7, 1992

CERTIFIED MAIL

Mr. David Croxton
EPA Project Coordinator
U.S. EPA
1200 Sixth Avenue, M/S HW-106
Seattle, WA 98101

Re: Burlington Environmental Inc. (BE) Pier 91 RFI Workplan

Enclosed are the two 90-day responses to USEPA's July 9, 1992 Conditional Comments to the Pier 91 RFI Workplan submitted to USEPA on April 17, 1992. BE responded to the items requiring a response within 21 days on July 30, 1992. The 90-day responses include a proposed pumping test workplan and a tidal monitoring workplan.

If you have any questions or require further information, please contact me at (206) 223-7596.

Sincerely,

John Stiller
Project Coordinator

cc: Galen Tritt - Ecology NWRO

USEPA RCRA
3012478

Burlington Environmental Inc.
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RESPONSES TO U.S. EPA CONDITIONAL COMMENTS FOR
"RCRA FACILITY INVESTIGATION WORK PLAN
BURLINGTON ENVIRONMENTAL INC.
PIER 91 FACILITY"

2) Hydrological Zone Interconnection: No direct methods are proposed to measure the amount of interconnection between the upper and lower water bearing zones through the silty-sand layer. Pump testing or some equivalent method is needed to provide more definitive data on the continuity and properties of the silty-sand layer. The importance of determining the properties of this layer are outlined in our original comments (comment #4). If a pump test is selected, it will require pumping groundwater from the lower water bearing zone with observation wells located in both the upper and lower zones. A large diameter well will be needed to pump sufficient water to run the test. In anticipation of the pump test, Burlington may want to construct one of the proposed deeper wells as a larger diameter well. Alternatively, an extraction well can be added to the current proposal for the purposes of this test.

If Burlington intends to construct one of the proposed wells as a larger diameter well rather than install an additional well, Burlington must notify EPA of the proposed well construction change within 21 days of receipt of this letter. The proposed pump test or equivalent method plan, and plans for constructing a new well if applicable, must be submitted to EPA within 90 days of receipt of this letter.

Response to comment (2):

In Burlington's initial response to EPA (submitted July 30, 1992) regarding this comment, Burlington proposed changing the location and construction of proposed deep-aquifer monitoring well CP-122B, changing the location (and designation) of proposed deep-aquifer monitoring well CP-107B, and adding a shallow-aquifer monitoring point near the new location of well CP-122B. The specific location changes were listed in that initial response. The specific construction changes were also listed, except that the construction of the shallow monitoring point near well CP-122B was not specified. Burlington proposes to construct this well as per the specifications for wells CP-111, CP-112, CP-113 and CP-114, as illustrated schematically in Figure C-2 of the RFI Work Plan (Burlington, 1992). This well will be given the designation "CP-122A". Burlington has prepared a pumping test work plan; it is included as Attachment 1.

3) Tidal Influence and Net Direction of Ground Water Flow: In order to determine the impact of tidal cycles on the net direction of ground water flow, a more comprehensive analysis with more frequent monitoring than the monthly water level measurement, is necessary. Monthly water level measurements can not discern the net effects of the entire tidal cycle on ground water flow. The proposed method should include measuring such variables as tidal stage, water levels in the wells, gradient changes through the tidal cycle, hydraulic conductivity of the screened strata, tidal efficiency, water elevation of surface water bodies, etc. The use of continuous recording transducers are recommended and modeling may be helpful in resolving the resulting vectors of ground water flow. Also, unless it can be demonstrated that seasonal differences would not alter the net effect of the tidal cycle, the proposed plan must include plans for monitoring the impacts of the tidal cycle in different seasons.

Burlington must submit plans for measuring the effects of the tidal cycle on ground water flow to EPA within 90 days of receipt of this letter.

Response to Comment (3):

Burlington has prepared a tidal monitoring work plan; it is included as Attachment 2.

REFERENCE

Burlington Environmental Inc. 1992. RCRA Facility Investigation Work Plan, Burlington Environmental Inc. Pier 91 Facility, Seattle, Washington. Prepared for Burlington Environmental Inc.

PUMPING TEST WORK PLAN
FOR RCRA FACILITY INVESTIGATION
BURLINGTON ENVIRONMENTAL INC.
PIER 91 FACILITY
SEATTLE, WASHINGTON

October 1992

Prepared for:

Burlington Environmental Inc.
Seattle, Washington

Project 624878

Prepared by:

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TABLE OF CONTENTS

1 PUMPING TEST SUMMARY

This section summarizes the purpose, objectives, schedule, and scope for the proposed pumping test.

1.1 Background and Purpose

This work plan outlines the pumping test proposed for the Burlington Environmental Inc. (Burlington) Pier 91 facility, as part of the RCRA Facility Investigation (RFI) to be conducted at that facility. An RFI Work Plan (Burlington, April 1992) for the Pier 91 facility was conditionally approved by the U.S. Environmental Protection Agency (USEPA) in July 1992 (USEPA, 1992). One of the conditions that the USEPA imposed as a requirement for final approval of the RFI Work Plan was that Burlington submit plans for the proposed pumping test. This work plan, if approved, is to become an addendum to the existing RFI Work Plan.

1.2 Objectives

The objectives of this pumping test are as follows:

- to infer the degree of hydraulic connection between the upper and lower water-bearing zones through the silty sand layer, using a direct method;
- to infer the hydraulic properties of the deep aquifer; and
- to check the consistency of other available information, such as slug test results and laboratory permeability measurements.

1.3 Schedule

The field activities of the pumping test will be conducted during a period following the installation and development of monitoring wells CP-106B, CP-122A and CP-122B. This timing is necessary because these wells, in addition to existing monitoring well CP-106A, are to be used for pumping or water-level observations during the test.

There will be a waiting period, of minimum duration 24 hours, between the completion of certain types of field activities (e.g., drilling, well installation and development, and slug testing), and the initiation of the pumping test. This waiting period is intended to minimize unknown disturbances of the groundwater levels in the area prior to the test. Such disturbances could complicate the interpretation of the pumping test data.

The RFI Work Plan (Burlington, April 1992) calls for laboratory permeability testing of samples from the silty sand layer. This schedule is intended to allow Burlington to complete the field portion of the pumping test and interpret the data after the results of the proposed permeability testing are available.

Finally, the pumping test will not be completed until after the proposed tidal monitoring has been completed. The response of groundwater levels to tidal forcing, if not accurately accounted for, may partially or fully mask the response to deep-aquifer pumping. This might render the test useless, or at least require reinterpretation following completion of the tidal monitoring study. Therefore, it is prudent to interpret the pumping test data after the tidal monitoring study has been completed.

1.4 Scope

A detailed description of the scope of this pumping test is given in the following sections. In summary, the scope includes the following elements:

- data collection;
- data analysis; and
- reporting.

The data collection element involves the acquisition of various types of data at selected time intervals throughout the test. Pertinent data include barometric pressure, tide levels, and groundwater levels. The data analysis element primarily involves the interpretation of the pumping test data, and its integration with hydraulic and stratigraphic data collected during previous site investigations, the proposed pumping test, and other ongoing RFI activities. The reporting element involves the description of test procedures and analysis methods, summary of data and analysis results, and discussion of the results and conclusions.

2 TEST DESCRIPTION

2.1 General Procedure

The pumping test is to involve a drawdown period during which water is pumped at a constant rate out of the deep-aquifer monitoring well CP-122B, followed by a recovery period of approximately equal duration, in which no pumping occurs. Water levels will be measured and recorded in both shallow and deep monitoring wells throughout both periods.

The exact duration of the drawdown period has not yet been determined, but is expected to be approximately 48 hours. The actual duration will depend on the measured response of the water levels. Ideally, the duration of the pumping period would be sufficient to effect an observable response in the shallow aquifer water levels. However, practical considerations limit the pumping period duration to a maximum 72 hours. Such considerations include the on-site water storage capacity, water testing and disposal costs, and test operating costs. An additional consideration in the choice of the test duration is that late-time water-level data are required to obtain reliable estimates of deep-aquifer hydraulic properties and to identify hydrogeologic boundaries.

Similarly, the pumping rate has not yet been determined. However, the rate is anticipated to be approximately 5 gallons per minute. This rate may need to be adjusted depending on the efficiency of the pumping well, aquifer thickness, and aquifer transmissivity and storage coefficient. Following well installation and slug testing, additional information will be available for estimating an appropriate pumping rate.

2.2 Decontamination

All equipment to be lowered into monitoring wells will be decontaminated according to the procedures specified in the RFI Work Plan (Burlington, April 1992). Such equipment includes:

- submersible pump housing, power cable and suspension line;
- pump discharge hose and pump/hose fitting;
- electronic water-level indicator probe and cable; and
- pressure transducer housings and cables.

2.3 Disposal of Discharge Water

Water discharged from the pumping well during the drawdown period of the pumping test will be conveyed, via pipes and/or hoses, to an on-site tank trailer or holding tank prior to disposal. The water will be managed as a wastestream, as per Burlington's standard operating procedures, prior to treatment and/or discharge at one of the Burlington treatment, storage, and disposal (TSD) facilities.

3 DATA COLLECTION

Subsections 3.1 through 3.3 outline efforts to collect data during the pumping test. Section 3.4 describes relevant data to be obtained from other sources.

3.1 Groundwater Levels

Water levels in shallow-aquifer monitoring wells CP-106A and CP-122A, and deep-aquifer monitoring wells CP-106B and CP-122B, will be measured throughout both the drawdown and recovery periods. Monitoring well CP-106A is an existing well; this well has been referred to as well CP-106 in the past. Monitoring wells CP-106B, CP-122A and CP-122B are proposed new wells. Water levels will be measured using pressure transducers and recorded at preprogrammed time intervals using an electronic data logger. The time intervals will correspond to the following schedule:

Log Cycle	Elapsed Time	Time Interval
1	0-5 seconds	0.5 second
2	5-20 seconds	1 second
3	20-120 seconds	5 seconds
4	2-10 minutes	0.5 minute
5	10-100 minutes	2 minutes
6	>100 minutes	10 minutes

In addition, the water levels in the wells will be measured periodically and recorded using one or more electronic water-level indicator(s). Measurements made with the water-level indicator(s) can be used as a check for the electronic data acquisition system, and may be used for backup in case of equipment failure.

3.2 Barometric Pressure

Barometric pressure will be measured and recorded hourly during both the drawdown and recovery periods of the pumping test, using either a portable barometer or a barometric pressure transducer with an electronic data logger.

3.3 Volumetric Discharge Rate

For a constant-discharge rate pumping test such as the one proposed here, it is very important to keep the discharge rate of the pump constant throughout the entire drawdown period. Variable discharge rates are difficult to monitor, complicate data interpretation, and may even render test results useless.

The discharge rate of the pump will be estimated and recorded periodically throughout the drawdown period of the test. The pump system will be adjusted as necessary to keep the discharge rate constant in time and close to the target value. The discharge rate will be estimated by measuring the amount of time that is required to fill a calibrated container, such as a plastic bucket, with the water stream that is discharged from the pumping well. The discharge will be measured where the outlet line from the pumping well enters the holding tank, so that the estimate is not biased by head loss differences.

3.4 Other Data

Interpretation of the pumping test data discussed above will be facilitated by additional site data. Potentially useful data from sources other than the pumping test include information from previous investigations and from other RFI activities. Relevant information collected during previous investigations includes the following (Sweet-Edwards/EMCON, Inc.; 1988, 1989):

- stratigraphic information;
- results of slug tests conducted in monitoring wells; and
- groundwater system tidal response data.

Relevant information to be collected through planned RFI activities includes the following:

- stratigraphic information collected during drilling of new monitoring wells;
- results of slug tests conducted in new monitoring wells;
- results of laboratory permeability testing of samples from the silty sand layer at the locations of the new deep wells; and
- results of the tidal monitoring program.

All of the activities that generate these data are to be conducted as part of the RFI and the test procedures and methods are described in the RFI Work Plan (Burlington, April 1992).

4 DATA ANALYSIS

Water-level data from the pumping test will be analyzed using standard aquifer test analysis methods, if possible. These methods include the use of log-log plots, semilog plots, and type-curve matching. Special software designed especially for this purpose (e.g., AQTESOLV™) is available and will be utilized unless the data appear to be inconsistent with the solution options, or other problems make its application unpractical or impossible. In that case, other methods may be used. Solution options that are likely to be applicable, and are available in the current version of the AQTESOLV™ software, are those based on the work of Hantush and Jacob (1955) and Hantush (1960).

The water-level response of the shallow-aquifer monitoring wells will be compared to that of the deep-aquifer wells, for the purpose of evaluating the degree of hydraulic connection between the shallow and deep aquifers. An attempt will be made to explain the observed differences and similarities using traditional porous medium flow theory. An attempt will also be made to differentiate the effect of deep-aquifer pumping from the effects of the observed barometric pressure fluctuations and tidal fluctuations.

5 REPORTING

After the pumping test is completed and all of the pertinent data have been collected, tabulated and analyzed, Burlington will prepare a written report on the pumping test. The report will describe field procedures followed during the pumping test, list raw data collected during the test, discuss other findings and observations, describe calculations used in the data interpretation, and present conclusions. The report will be completed within 45 days of completion of the pumping test. If, at that time, the draft RFI report has not yet been submitted to the USEPA, the pumping test report will be included as part of the draft RFI report. Otherwise, the pumping test report will be submitted to the USEPA as an addendum to the draft RFI report.

REFERENCES

Burlington Environmental Inc. April 1992. RCRA Facility Investigation Work Plan, Burlington Environmental Inc. Pier 91 Facility, Seattle, Washington. Prepared for Burlington Environmental Inc.

Hantush, M.S. and C.E. Jacob. 1955. Non-steady Radial Flow in an Infinite Leaky Aquifer. Transactions of the American Geophysical Union. v. 36, pp.95-100.

Hantush, M.S. 1960. Modification of the Theory of Leaky Aquifers. Journal of Geophysical Research. v. 65, no. 11, pp. 3713-3725.

Sweet-Edwards/EMCON, Inc. 1988. Phase I Hydrogeological Investigation, Chemical Processors, Inc. Pier 91 Facility, Seattle, Washington. Prepared for Chemical Processors, Inc. Seattle, Washington.

_____. 1989. Hydrogeologic Investigation, Pier 91 Facility, Chemical Processors, Inc. Prepared for Chemical Processors, Inc. Seattle, Washington.

U.S. Environmental Protection Agency. July 9, 1992. Letter from Michael Gearheard, USEPA, to John Stiller, Burlington Environmental Inc.

TIDAL MONITORING WORK PLAN
FOR RCRA FACILITY INVESTIGATION
BURLINGTON ENVIRONMENTAL INC.
PIER 91 FACILITY
SEATTLE, WASHINGTON

October 1992

Prepared for:

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Seattle, Washington 98134

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TABLE OF CONTENTS

1 TIDAL MONITORING PROGRAM SUMMARY

1.1 Background and Purpose

This work plan outlines the proposed tidal monitoring program to be conducted as part of the RCRA Facility Investigation (RFI) at the Burlington Environmental Inc. (Burlington) Pier 91 facility. An RFI Work Plan (Burlington, April 1992) for the Pier 91 facility was conditionally approved by the U.S. Environmental Protection Agency (USEPA) in July 1992 (USEPA, 1992). One of the conditions that the USEPA imposed as a requirement for final approval of the RFI Work Plan was that Burlington submit plans for measuring the effects of the tidal cycle on groundwater flow. This work plan is intended to satisfy that requirement, and to provide a basis for conducting the tidal monitoring program.

1.2 Objectives

The overall objective of the tidal monitoring program is, as stated in the RFI Work Plan approval letter (USEPA, 1992), "... to determine the impact of tidal cycles on the net direction of ground water flow ...". More specific objectives include the following:

- to measure the diurnal variations of groundwater levels within the shallow and deep aquifers;
- to understand the effects of tidal forcing on groundwater levels within the shallow and deep aquifers;
- to understand the effects of tidal forcing on the horizontal components of groundwater flow, within both the shallow and deep aquifers at the site;
- to understand the effects of tidal forcing on the vertical groundwater flow between the shallow and deep aquifers;

- to estimate the time-averaged horizontal components of groundwater flow, within both the shallow and deep aquifers;

- to estimate the time-averaged vertical components of groundwater flow between the shallow and deep aquifers;

- to understand the effect of Lake Jacobs on the tidally-forced groundwater system; and

- to understand any seasonal or barometric variations in these tidal effects.

1.3 Schedule

Tidal monitoring will be conducted during two 75-hour tidal monitoring periods. The first tidal monitoring period will occur in February 1993, and the second in August 1993. The rationale for multiple tidal monitoring periods is given in Section 4.4, Seasonal Variation.

This schedule will allow Burlington to perform tidal monitoring after the proposed laboratory permeability tests and the field hydraulic tests (see Section 3.5) have been completed. Since groundwater flow is determined in part by the hydraulic properties of the subsurface, it is important for these data to be available at the time the tidal monitoring data are interpreted.

It is also important that all drilling, well installation, well development, and slug testing activities be completed before the tidal monitoring is initiated. These activities could potentially cause unknown temporary disturbances to the potentiometric surface of one or both aquifers. Such disturbances could complicate the interpretation of tidal response data. In addition, it is critical that the data collected during these activities be available before the tidal monitoring begins, so that Burlington can thoroughly assess the appropriateness of, and make an informed selection of, wells to be used for tidal monitoring.

1.4 Scope

A detailed description of the scope of this program is given in the following sections. In summary, the scope consists of the following elements:

- data collection;
- data analysis and interpretation; and
- reporting.

The data collection phase involves the acquisition of various types of data, periodically over two 75-hour tidal monitoring periods. Pertinent data include groundwater levels, barometric pressures, lake stages, and tide levels. The data analysis and interpretation phase involves the estimation of the time-averaged system behavior. This includes the calculation of numerical measures of the groundwater system's response to tidal forcing. The reporting phase involves report preparation, and submittal to the USEPA according to the timeframe given in Section 5.

2 PREVIOUS WORK

2.1 On-Site Tidal Monitoring

The most relevant work performed to date to infer the tidal response of the groundwater system is that of Sweet-Edwards/EMCON (SE/E) (SE/E, 1989). This is the only known tidal study ever completed for Burlington's Pier 91 facility. A brief summary of this work is given below.

On May 6, 1988, a water-level change of 1.6 feet was measured in the deep-aquifer monitoring well CP-103B; the corresponding tide-level change was reported to be 13 feet (SE/E, 1989). SE/E also noted that the water-level fluctuation lagged the tide-level fluctuation by about 29 minutes.

On February 21-22, 1989, water levels in wells CP-108A and CP-108B were measured over a 24-hour period (from 15:22 on February 21, 1989, to 15:27 on February 22, 1989) using pressure transducers and an electronic data logger. Water levels were measured in wells CP-104B, CP-107, CP-109, and CP-110 during the last six hours of this same time period using an electronic water-level indicator. The tide level reportedly changed by approximately 13 feet during this period (SE/E, 1989). The measured water-level fluctuation in well CP-108B, which lies approximately 360 feet from Elliott Bay, was reported to have an amplitude of approximately 3.6 feet and to lag the tide-level fluctuation by approximately 40 minutes. No significant influence was reported for deep-aquifer well CP-104B, which lies approximately 730 feet from Elliott Bay. Similarly, no significant influence was reported in shallow-aquifer monitoring wells CP-107, CP-108A, CP-109, and CP-110. Based on these results, SE/E concluded that tidal influence is not expected to be significant at a distance greater than 400 feet from the shore (SE/E, 1989).

2.2 Other Tidal Monitoring

In addition to the work by Sweet-Edwards/EMCON discussed above, Converse GES performed tidal monitoring in the vicinity of the Pier 91 facility while completing studies for Pacific Northern Oil (Converse GES; 1989, 1990a, 1990b). Converse GES measured water levels in three monitoring wells located west of Lake Jacobs, over a period of approximately 27 hours during November 1989. Two of the wells are approximately 15 feet west of Lake Jacobs; the other well was approximately 50 feet west of Lake Jacobs. This area is approximately 200 feet southwest of the property that Burlington leases from the Port of Seattle, and lies between the Pier 91 facility and the shore of Elliott Bay, which lies approximately 240 feet west of Lake Jacobs. Water levels were measured using pressure transducers and an electronic data logger (Converse GES, 1990a). According to the boring logs included in Appendix A of the January 1990 report (Converse GES, 1990a), all three of the wells were completed at depths less than 20 feet below ground surface.

Three high tides and two low tides reportedly occurred during the tidal monitoring period. Graphs of water level versus time for some of the wells are presented in the reports. Total net fluctuations of water levels in the three wells varied from approximately 0.23 foot to 0.34 foot. Water-level fluctuations in all three wells were reported to be in phase with the tidal variations. The hydraulic gradient was inferred from water-level measurements, and was observed to change direction approximately 25 degrees over the monitoring period. The direction was toward the southeast or south-southeast. Converse GES (1990b) also obtained water-level measurements via a stilling well in Lake Jacobs over a 24-hour period during the tidal monitoring period. The total fluctuation in water level was approximately 0.05 foot.

Pacific Groundwater Group and Converse Consultants Northwest (PGG/CCN) present time plots of water-level measurements made during July 28 and 29, 1988, in five piezometers located in the short fill (PGG/CCN, 1990). The short fill is the area bounded to the north by Lake Jacobs and to the south by Smith Cove of Elliott Bay. These results were reportedly used for calibration of a hydraulic/transport model. The piezometers were completed in artificially-emplaced fill materials.

The relationship between the response of water levels in the short fill and in the fill materials west of Lake Jacobs, and that of water levels in the units underlying the property leased by Burlington, if any, is not well known. Because the shallow subsurface conditions in the areas south and west of Lake Jacobs may differ from that of the leased property, and the groundwater flow is two- or three-dimensional, a simple relationship between the responses in the two areas is not likely to be found.

3 DATA COLLECTION

Sections 3.1 through 3.4 describe data to be collected during each tidal monitoring period. Section 3.5 describes related data to be collected as part of other RFI activities.

3.1 Tide Level

The National Ocean Service (NOS) continuously measures tide levels at the Colman Docks area of Elliott Bay. The distance from this location to the Pier 91 facility is less than five miles. Tide measurement results are available in data sets having any one of the following descriptions:

- one tide level measurement per six minutes;
- one tide level measurement per hour; or
- times and levels of high and low water.

In the Seattle area the tide is semidiurnal; two high tides and two low tides occur per tidal cycle (approximately 25 hours). Burlington will obtain a data set that corresponds to the tidal monitoring period, and that includes a measurement frequency of one per hour or greater. The data set will be obtained from the NOS Tidal Datum Section in Rockville, Maryland. Normally such data are not made available to the public until approximately 30 days following the last day of the month in which the data are collected. The data set will include information on the datum level, the time system (e.g., Pacific Standard Time), the measurement frequency, and the measurement units. Burlington will also request that the NOS provide specifications on the accuracy and precision of their tide measurement system. If such information is provided to Burlington, it will be included in the final written report (see Section 5).

3.2 Groundwater Levels

Water levels will be measured in three two-well nests regularly over each of the two 75-hour tidal monitoring periods. Each well nest consists of a pair of wells - one completed in the shallow aquifer and one completed in the deep aquifer. The particular well nests to be utilized for tidal monitoring have not yet been determined. An attempt will be made to select three well nests that surround a relatively large portion of the facility so that the observations are approximately representative of the entire facility. For example, one likely choice is the combination CP-103, CP-104, and CP-108. The final selection will be made only after the drilling, well installation, well development, and slug testing activities have been completed. With this approach, additional information collected during these activities can be utilized in the selection process.

The duration of each tidal monitoring period is approximately equal to that suggested by Serfes (1991) for determining the mean hydraulic gradient of a tidally-influenced groundwater system. Since the majority of the total variation in water levels is expected to be that associated with tidal forcing, and this forcing has a period of approximately 12.5 hours, a measurement frequency of one per hour should be adequate to characterize the tidal response of the groundwater system.

The measurement frequency will be at least one per hour. These measurements will be made using an electronic data acquisition/storage system consisting of a data logger and pressure transducers. One transducer will be placed in each of the six wells. In addition, water levels in the wells will be measured periodically using an electronic water-level indicator. Data collected using the electronic water-level indicator can be used as a check for the electronic data acquisition system, and can be used as a backup in case of equipment failure. Equipment to be lowered down wells, including any equipment to be lowered into Lake Jacobs (see Section 3.3), will be decontaminated prior to use according to the decontamination procedures specified in the RFI Work Plan (Burlington, April 1992).

3.3 Barometric Pressure

Barometric pressure will be monitored during each tidal monitoring period using either a portable barometer or a barometric pressure transducer and an electronic data logger. The measurement frequency will be at least one per hour. The collection of barometric pressure information is necessary to differentiate groundwater response to tidal effects from groundwater response to barometric effects.

3.4 Lake Stage

The stage of Lake Jacobs will be measured at least hourly during each tidal monitoring period. A consultant's report (Converse GES, 1990) mentions a stilling well that reportedly was used for obtaining stage measurements at Lake Jacobs during a previous investigation. If the stilling well is found to be operable, and Burlington can obtain authorization to utilize it, the hourly stage measurements will be obtained from this well during the tidal monitoring period. If Burlington can not obtain the necessary authorization or is unable to use the stilling well for some other reason (e.g., if the well is gone or is found to be inoperable), alternate arrangements will be made to obtain the stage measurements. In that case, a temporary stilling well will be installed in Lake Jacobs by securing a clean PVC pipe to a stationary object on the lakeshore or on the dock at the lake. The stage will be measured using either an electronic water-level indicator or a pressure transducer with an electronic data logger.

3.5 Hydraulic Conductivity

Although some hydraulic conductivity test data from previous investigations (Sweet-Edwards/EMCON; 1988, 1989) are available, the RFI Work Plan specifies the collection of additional hydraulic data. Methods proposed for the collection of these data include laboratory permeability testing of samples from the silty sand layer, and slug testing of the new monitoring wells. These activities will be completed before the tidal monitoring is performed. In addition, as part of Burlington's response to USEPA's comments on the RFI Work Plan, Burlington has proposed a deep-aquifer pumping test. All of these activities are to be conducted as part of the RFI and are described in the RFI Work Plan. Therefore, although these activities are related to the tidal monitoring effort, they are not considered to be within the scope of this tidal monitoring program.

4 DATA ANALYSIS

Sections 4.1 through 4.3 outline analyses to be performed on the data collected from each tidal monitoring period, while Section 4.4 describes the analysis of seasonal effects.

4.1 Hydraulic Gradients

In principle, the direction and specific discharge of flowing groundwater can be predicted if the hydraulic gradient and the hydraulic conductivity are known. As such, the hydraulic gradient is a useful indicator of the tendency for groundwater motion. The hydraulic gradient is a vector with three directional components. These include two horizontal components and a vertical component.

4.1.1 Horizontal Components

The horizontal components (x, y) of the hydraulic gradient in the shallow aquifer will be estimated using the water-level measurements from the three shallow-completion wells (see Section 3.2). These calculations will be based on the assumption that the flow in the aquifer is approximately horizontal. One estimate of the horizontal component will be provided for each set of water-level measurements collected during the tidal monitoring period. For example, if water levels are measured twice per hour, then two gradient estimates will be compiled for every hour of tidal monitoring. The same type of analysis will be performed to estimate the horizontal gradient in the deep aquifer.

4.1.2 Vertical Component

Burlington will estimate the vertical hydraulic gradient across the silty sand layer at each of the three well nests where water-level measurements are made. The vertical hydraulic gradient estimate will be calculated as the difference between the shallow-aquifer and deep-aquifer water levels, divided by the estimated thickness of the silty-sand layer. One such estimate will be provided for each set of water-level measurements collected during the tidal monitoring period. For example, if water levels are measured twice per hour, then two vertical gradient estimates will be compiled per well nest, for every hour of tidal monitoring.

4.2 Time-Averaged Hydraulic Response

One of the objectives of this study is to infer the time-averaged or net groundwater flow beneath the site. This requires the estimation of time-averaged water levels or hydraulic gradients. The following subsections describe how time-averaged quantities will be estimated.

4.2.1 Groundwater Levels

Burlington will tabulate the time-averaged groundwater levels in all six of the monitoring wells, for each 75-hour tidal monitoring period. The time-averaged groundwater level in each well will be estimated by calculating the arithmetic average of the water-level measurements from that tidal monitoring period. Other methods for filtering groundwater level data, such as those suggested by Serfes (1991) may also be used. The method(s) utilized will be specified in the final report.

4.2.2 Hydraulic Gradients

The time-averaged equivalent of the following hydraulic gradients will be estimated and tabulated:

- horizontal components of the hydraulic gradient in the shallow aquifer;
- horizontal components of the hydraulic gradient in the deep aquifer;
- vertical component of the hydraulic gradient across the silty sand layer, at all three well nests where water levels are measured.

The time-averaged gradients will be estimated by calculating the gradients of the time-averaged groundwater levels for each tidal monitoring period.

4.3 Tidal Response Parameters

The characteristics of the tidal response will be expressed using three parameters. These parameters, which include the amplitude, phase (time lag), and tidal efficiency, will be estimated and tabulated for each tidal monitoring period:

- amplitudes and phases of measured water-level fluctuations in all six of the monitoring wells (three two-well nests);
- amplitude and phase of measured stage of Lake Jacobs;
- amplitude and phase of the tidal fluctuation in Elliott Bay; and

- tidal efficiencies of the shallow and deep aquifers, at all three well nests.

Tidal efficiency is defined as the ratio of the amplitude of groundwater-level fluctuations to the amplitude of tide level fluctuations (Todd, 1980). The amplitudes of these quantities can be determined various ways, including graphically, or by calculation of root-mean-square or standard deviation (see Erskine, 1991). The phases can also be determined either graphically or by a numerical procedure such as least-squares (Erskine, 1991). For each case, the method of calculation will be specified in the final report.

4.4 Seasonal Effects

Tidal monitoring and analysis will be conducted during two distinct periods, in order to infer seasonal variations in the tidal response of the groundwater system. The two tidal monitoring periods will occur approximately at the times of high and low groundwater level at the site. Data from monthly water-level measurements indicate that these are likely to occur during the months of February and August, respectively. The results from the two tidal monitoring periods will be compared, to infer seasonal variations in the groundwater system's tidal response.

5 REPORTING

After the second tidal monitoring period, when all of the pertinent data have been obtained and analyzed, Burlington will prepare a final written report. The report will contain all of the data collected during both tidal monitoring periods, and the results of calculations pertaining to the quantities discussed in Section 4 (above). The report will be submitted to the USEPA within 45 days of Burlington's receipt of the required tide level data from the NOS.

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